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## INDUSTRIAL WOOD COMBUSTION SYSTEMS

BY

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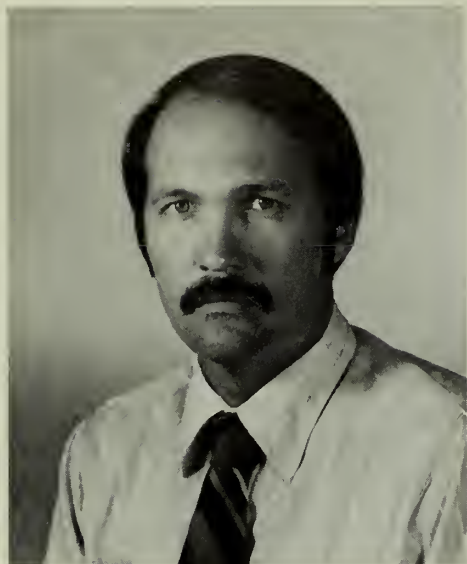
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# **INDUSTRIAL WOOD COMBUSTION SYSTEMS**

**BY**

**WILLIAM S. BULPITT, CAROL L. ATON**

**AND J. FRED ALLEN**

## **BACKGROUND**

Since steam power began to be an important source of energy in the eighteenth century, there has been a gradual evolution of hardware to the point we find ourselves today. The original fuel for steam production in this country was, of course, wood. As coal gained more widespread use, wood burning for industrial steam production became almost a lost art. In fact, coal and wood both nearly disappeared from the industrial scene in the southeast with the switchover to

natural gas and oil as boiler fuels in the 1940's and 1950's. Wood burning systems were not ignored by all industries, however. During the past 50 years, the forest products industries have seen the gradual development of wood burning boilers from rather primitive pile burners to units that are capable of producing up to 50,000 lb/hr of steam at pressures that rival the steam pressures found in central utility plants.

Boilers may be divided into two gener-

al classes--firetube boilers and watertube boilers. As the designations indicate, in the firetube design, the combustion gases travel through steel tubes passing through a water tank. In the watertube design, the water passes through steel tubes that are heated on the outside by the hot gases from the combustion process. Today many people have the tendency to dismiss the firetube boiler as an old-fashioned design, but this is not always the case. There are many applications where

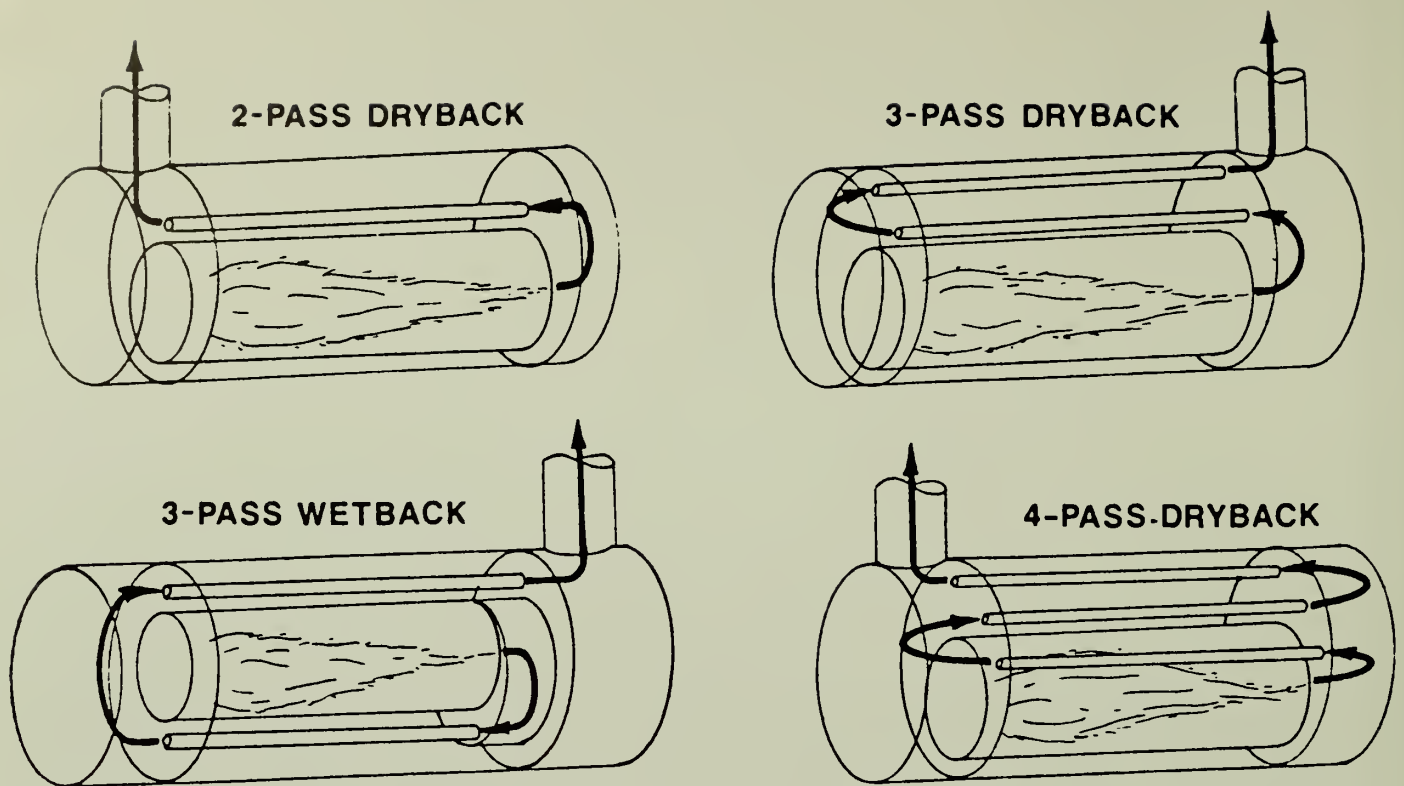


Figure 1

## FIRETUBE BOILER GAS FLOW PATTERNS

the firetube unit has distinct advantages over a watertube unit, particularly in light and medium industrial applications. Figure 1 illustrates several configurations used in firetube boilers while Figure 2 illustrates a circulation pattern typical of a watertube boiler.

Besides the firetube and watertube classifications, boiler designations can be made in another manner: boilers can be "package" boilers or "field-erected" boilers. These designations can cause some confusion since virtually all wood burning units require some field erection. A package boiler generally can be shipped over land with normal transportation methods such as flat-bed truck or railcar. The major boiler components are in one assembly and can often be lifted right onto a simple foundation and piped into an existing system. As a result, the package boiler requires far less labor before startup than a field-erected unit. The field-erected unit often requires individual welding of boiler tubes and the entire fabrication of a steel framework. In other

words, the boiler is completely built up at the job site from all the component parts, while the package boiler is nearly complete when it leaves the factory. Package boilers in the 100,000 lb/hr range have been shipped for gas/oil firing, but the larger combustion volumes necessary for wood units generally limit the top size for a wood fired package boiler to less than 50,000 lb/hr. As one might expect, field-erected boilers cost more than package boilers, and construction times are significantly longer.

## CLASSIFICATION OF WOOD COMBUSTION SYSTEMS

There are many different systems available today for burning wood in an industrial setting. Most of these systems fall into one of the following general classes:

Wood Fired Package Boilers  
Suspension and Cyclone Burners

Fluidized Bed Combustors  
Pyrolysis Systems  
Gasification Systems  
Field Erected Wood Boilers

Each of these classes will be considered in further detail.

## WOOD FIRED PACKAGE BOILERS

There are many manufacturers in the wood package boiler field today. In general, it can be said that the larger and perhaps better known manufacturers (Babcock and Wilcox, Combustion Engineering, Riley Stoker, Foster-Wheeler, etc.) are not really interested in building small (less than 50,000 lb/hr) boilers for light and medium sized commercial and industrial operations. This gap has been filled quite nicely by a number of smaller manufacturers; and as wood energy use has grown, the market has become more and more competitive.



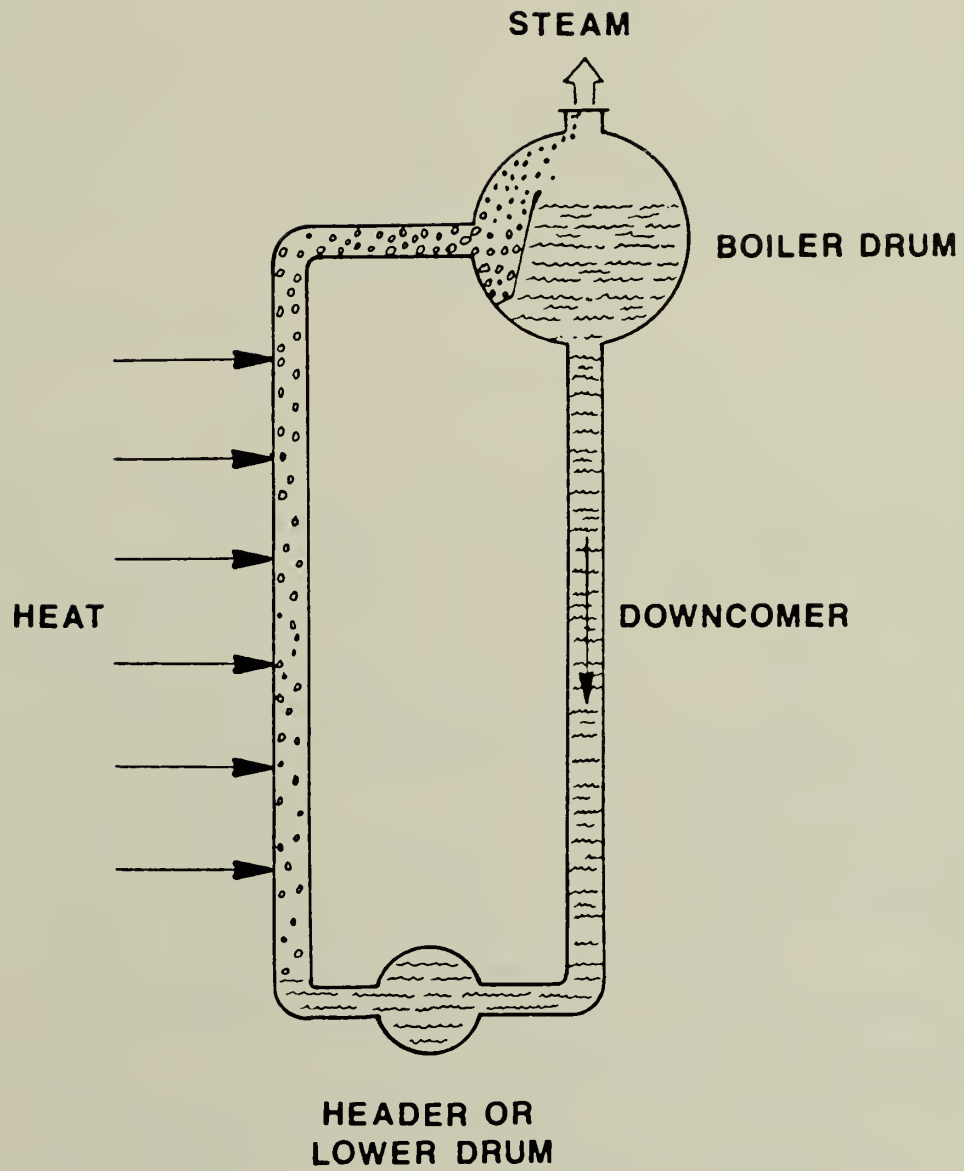


Figure 2

WATER CIRCULATION PATTERN IN A WATERTUBE BOILER

One of the older wood firing designs is the horizontal return tube (HRT) boiler. This type of unit was almost considered obsolete for a time, but in recent years it has seen a resurgence in sales. A typical HRT boiler is shown in Figure 3. The HRT is a firetube boiler which is basically a two-pass design. The steel boiler shell is supported by a refractory furnace, which helps these units to burn wet wood chips and residue ranging up to 60% moisture content. Operating pressures of HRT's are generally limited to 300 psi, and steam production is generally limited to 35,000 lb/hr or less. Some units are able

to meet emission regulations using only mechanical collectors.

There are several other types of firetube wood boilers including compact three-pass types that perform well on furniture plant waste and other dry material less than 20% moisture content. These boilers may perform with a thermal efficiency up to 80%. Another type of firetube boiler is shown in Figure 4. It is equipped with an underfeed stoker capable of burning wood, coal, or combinations of the two fuels with oil and natural gas backup.

Several smaller manufacturers produce

watertube boilers suitable for burning wood. One type that has been installed in more than 60 locations uses a refractory-lined cell burner with preheated underfire air. Most of the combustion takes place in the cell, and the hot flue gases are discharged into the watertube section.

The first cost of wood burning package boilers can be quite high, as shown in Figure 5. The cost curves in this figure are based on typical "turnkey" jobs installed by various boiler manufacturers and include fuel metering, controls, a limited amount of wood handling equipment, and air pollution control devices.

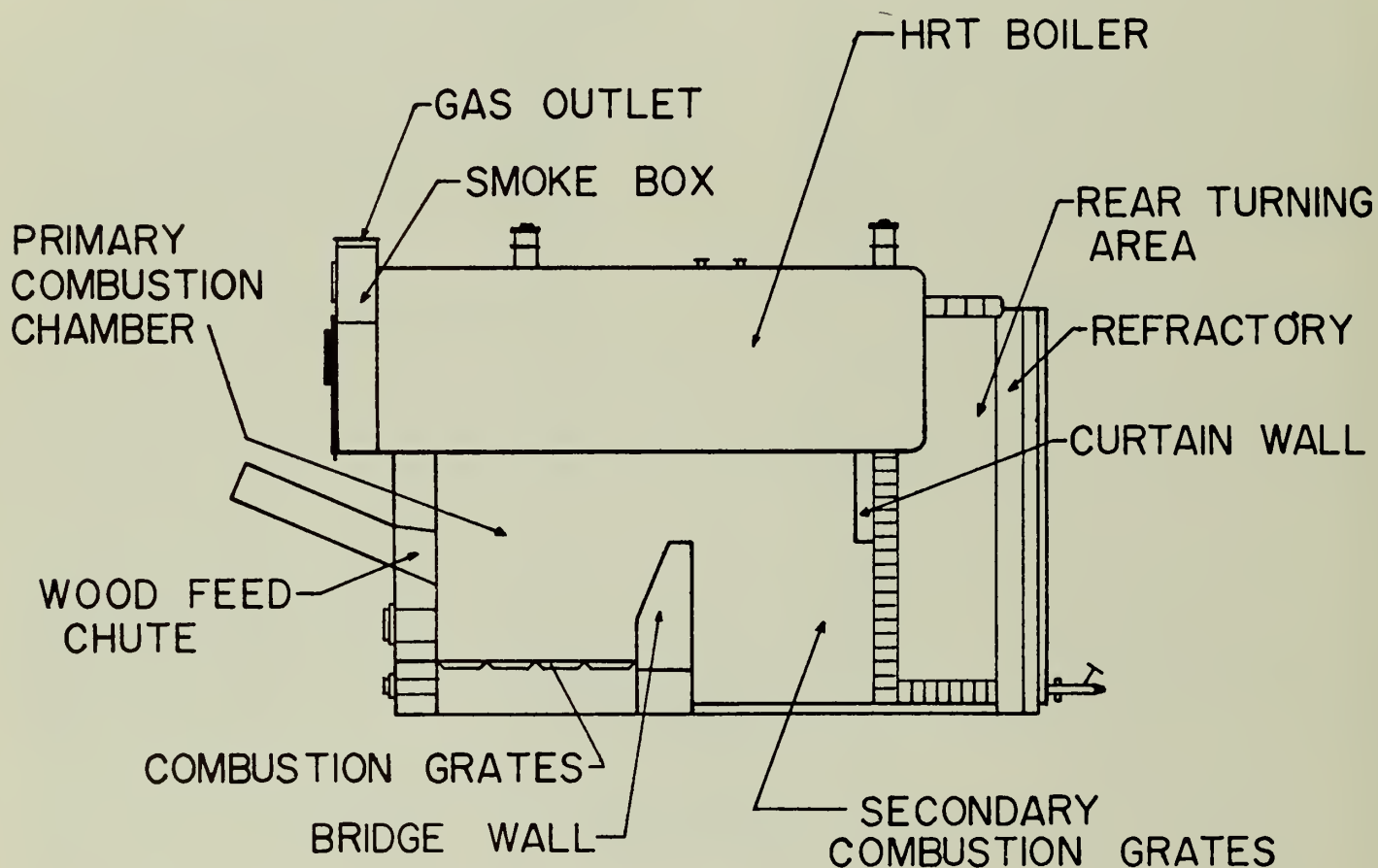


Figure 3

HRT BOILER FOR WOOD FIRING  
(Courtesy Industrial Boiler Co.)

The less expensive range of boilers are generally the ones with the least flexibility with regard to the quality of the fuel that may be burned. Even the smallest package boilers require a given amount of solids handling equipment and control systems so that the cost per pound of steam is much higher for the smaller systems. As can be seen from Figure 5, a given size of wood package boiler will generally have a first cost of 3 to 4 times that of a comparable gas/oil boiler.

It may be difficult to retrofit an existing steam plant with a wood fired package boiler due to space limitations. Wood systems generally require a greater area than for gas or oil dictating a larger size for a given steam output.

The major conclusion to be drawn a-

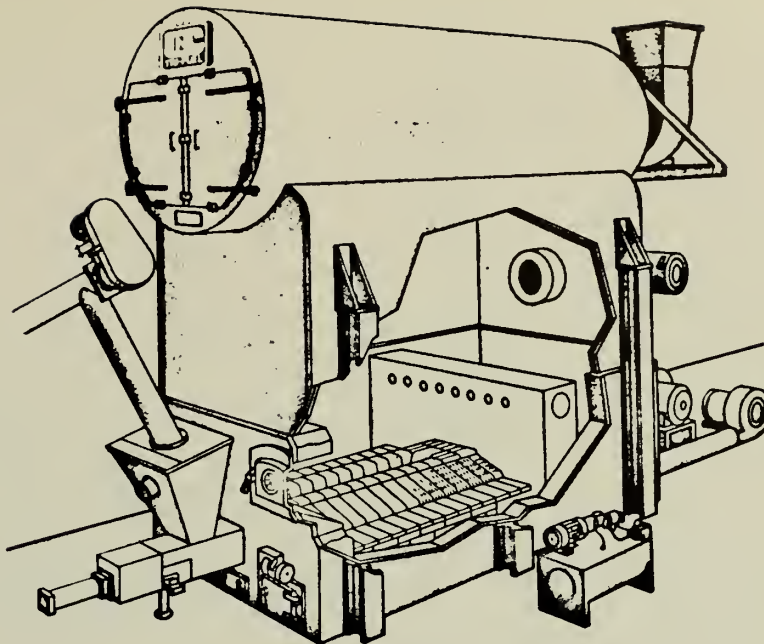


Figure 4

THREE-PASS WOOD BOILER  
(Courtesy Combustion Service & Equipment Co.)

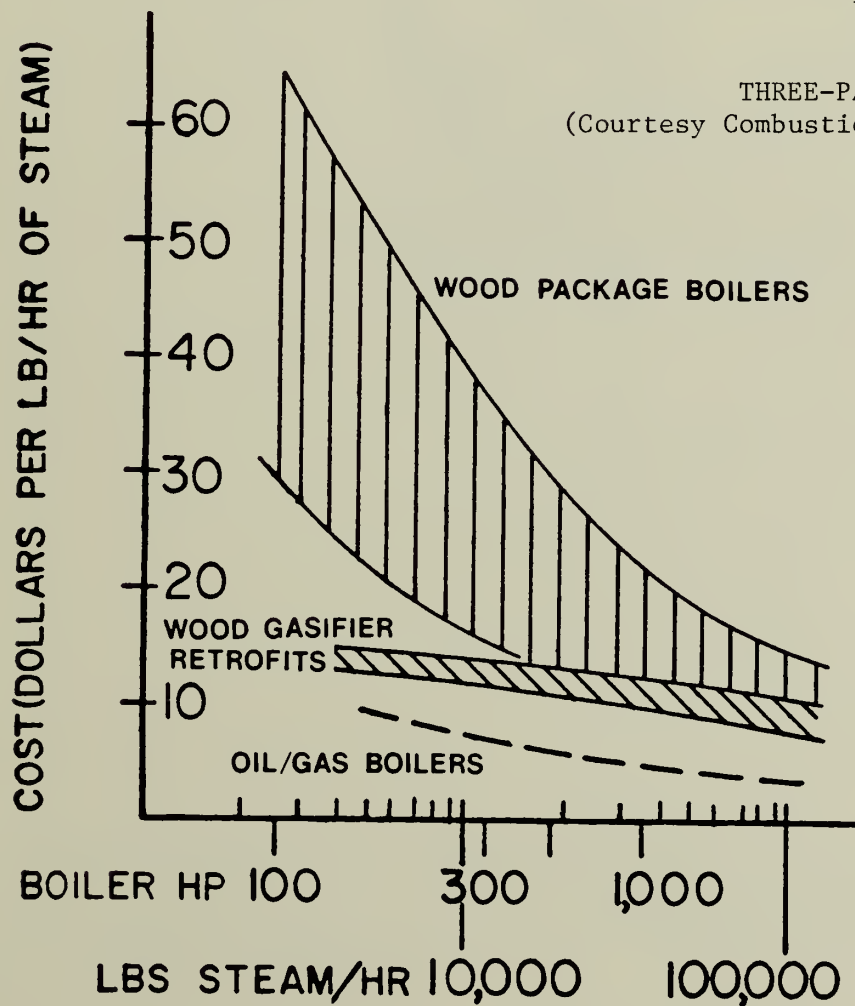


Figure 5

Cost of Wood Energy Systems

bout wood fired package boilers is that, as a class, they represent a system that is considered fully commercial. The cost will be substantially higher than the traditional gas/oil package boiler, but the pay-back time due to fuel cost savings can be attractive.

## SUSPENSION AND CYCLONE BURNERS

The cyclone furnace for burning pulverized coal has enjoyed widespread use on utility boilers for many years. The fuel is very finely ground and blown into the furnace almost as a gas. As a result, the combustion process is very efficient, and fly ash problems are easily dealt with.

Variations on the cyclone furnace concept have been developed for burning wood waste as well, but there are certain limitations that can hamper the feasibility for using these systems in many applications. The wood residue must be dry, and it must be hammermilled or hogged to fairly fine particles. In spite of these requirements, several companies have plac-

ed a number of these units in industrial plants, largely in the forest products industry. They have been used for firing directly into boilers, for product drying in rotary dryers, and for lumber dry kiln and veneer dryer applications. A typical cyclone burner is shown in Figure 6. In this particular unit, wood residue is blown tangentially through a series of manifolds from a pneumatic conveying system. Ash must be removed from the combustion chamber periodically, but otherwise the operation is fairly automatic. Cyclone wood burners generally range from 5 million Btu/hr to 60 million Btu/hr in single units.

## FLUIDIZED BED COMBUSTORS

The fluidized bed combustor has enjoyed much publicity over the past several years, particularly as an alternate combustion system for coal burning. Basically, a fluidized bed relies on a combustion chamber that has many holes drilled in the floor through which underfire air passes. This air blows through the "bed" which consists of small particles of sand, limestone, or other solid material. The bed is kept in suspension by the fans and is heated initially by an auxiliary fuel. When the bed reaches a temperature sufficiently high to ignite the fuel to be burned, the auxiliary fuel can be shut off and the solid fuel introduced. The turbulent mixing action of the hot bed material helps ensure that the fuel is burned completely.

In wood burning systems, the fluidized bed combustors have shown promise as devices capable of burning wet fuels or fuels of irregular sizes and shapes. In addition, other waste materials such as carpet scraps and peanut shells may be burned in conjunction with the wood. Several companies are actively marketing various fluidized bed systems, and many units have been operated successfully in the forest products industry. Possible drawbacks include relatively high first cost, maintenance requirements greater than a conventional boiler for the same capacity, and high power requirements for the fans.

One design of fluidized beds used for wood firing is shown in Figure 7. This unit is compact and is installed as a package unit. Gas and oil auxiliary fuel, provided manually, is necessary for startup. A multiclone collector is used for pollution control. The advantages to fluidized beds for wood waste are the possibility of burning wet fuel of inconsistent sizes and shapes. It may be expected that the fluidized beds require higher maintenance

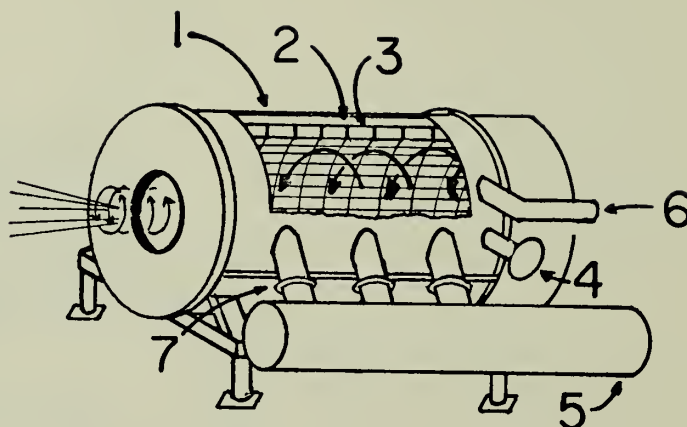
than conventional wood burners, and that more highly skilled operators may be necessary to operate them.

## PYROLYSIS SYSTEMS

Pyrolysis can be defined as burning without oxygen. The process involves the physical and chemical decomposition of solid organic matter caused by the action of heat in the absence of oxygen. Wood

can be pyrolyzed to produce charcoal, and coal can be pyrolyzed to produce gas. Due to the intense heat in a pyrolytic reactor, complex organic compounds can be broken down into simpler chemical products. These products include liquids, gases, and carbon char residue.

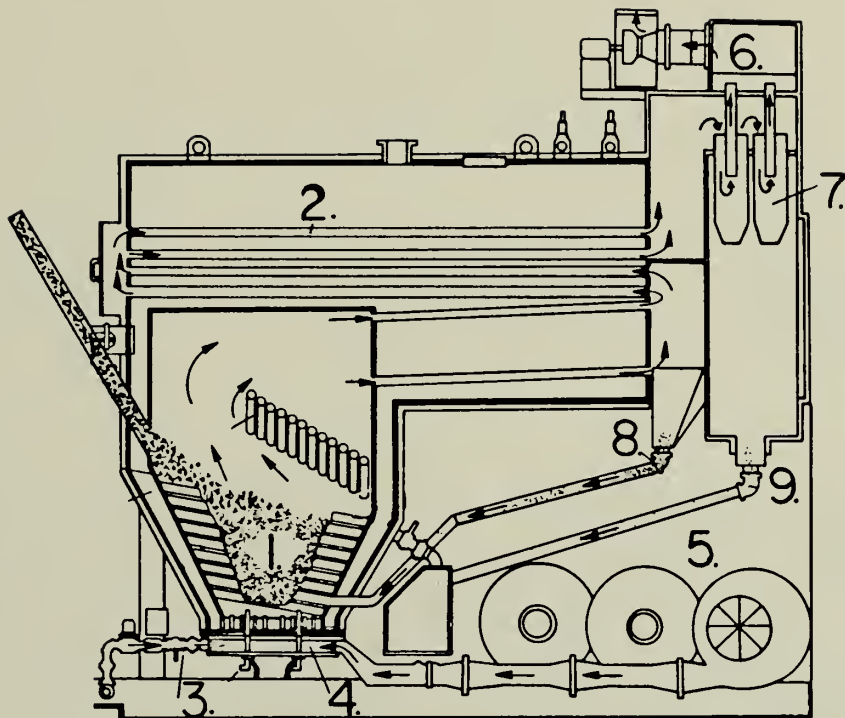
Various types of pyrolysis processes have been developed in recent years by many different companies. One of their goals has been the production of useful fuels from municipal solid waste (MSW).



- (1) Insulation
- (2) Air Plenum
- (3) Refractory
- (4) Auxiliary Burner
- (5) Combustion Air Manifold
- (6) Fuel Inlet
- (7) Butterfly Valve

Figure 6  
A Typical Cyclone Burner





- (1) Fluidized Bed
- (2) Firetube Heating Surface
- (3) Gas Train
- (4) Oil Train
- (5) Forced Draft Fans
- (6) Induced Draft Fan
- (7) Cyclone Collector
- (8) Carbon Reinjection
- (9) Ash Disposal

Figure 7

A Fluidized Bed Suitable for Wood Firing  
(Source: Johnston Co.)

However, limiting the feedstock to purely organic matter, such as wood waste or agricultural residues, simplifies the problem of dealing with large quantities of refuse. Figure 8 shows a pyrolysis system that has been successfully operated at Georgia Tech on wood chips. The system can produce varying amounts of oil, gas, and char according to the control configuration. Energy content of the products, of course, depends on the feedstock; but in general, the heating value of the oil is approximately 9,000 Btu/lb, heating value of the gas produced by the pyrolysis system varies from 3,200 Btu/lb to 4,500 Btu/lb and the heating value of the char varies from 12,300 to 13,500 Btu per pound.

Cost data for wood pyrolysis systems are difficult to obtain since the systems currently available are still largely in the prototype stages. The systems tend to be rather complicated, and as a result, they

can be expensive. The attractive feature of the pyrolysis system is the possibility for sale of a high value product (char), but the purchaser should be quite certain about the existence of a market before investing in a pyrolysis system.

## WOOD GASIFIERS

The transformation of solid biomass into a gaseous fuel is not a new concept, but the idea has realized a renewed interest over the past several years. In the true sense, wood gasifiers are a subset of the wood pyrolysis units discussed in the previous section.

There are many different equipment configurations in use for wood gasification, but the units that are generating the most interest today are the air gasifiers. These gasifiers typically pass approxi-

mately 25% of theoretical combustion air through a glowing char bed. Several chemical reactions take place that result in a low heating value gas of 100 to 200 Btu/ft<sup>3</sup>. Both of these gases, of course, have energy densities much lower than natural gas (1,000 Btu/ft<sup>3</sup>), but the gas can still be a useful fuel for close-coupled applications.

There has been considerable interest recently in wood gasification as a retrofit technology for conventional gas/oil fired boilers. A low Btu burner can be substituted for the existing burner and fired with the "producer" gas. Some derating of the boiler would occur and the severity of this derating would depend on the particular design of the boiler.

The main problem associated with wood gasifiers is undesirable constituents in the gas including certain tars and acids. These have a tendency to condense in

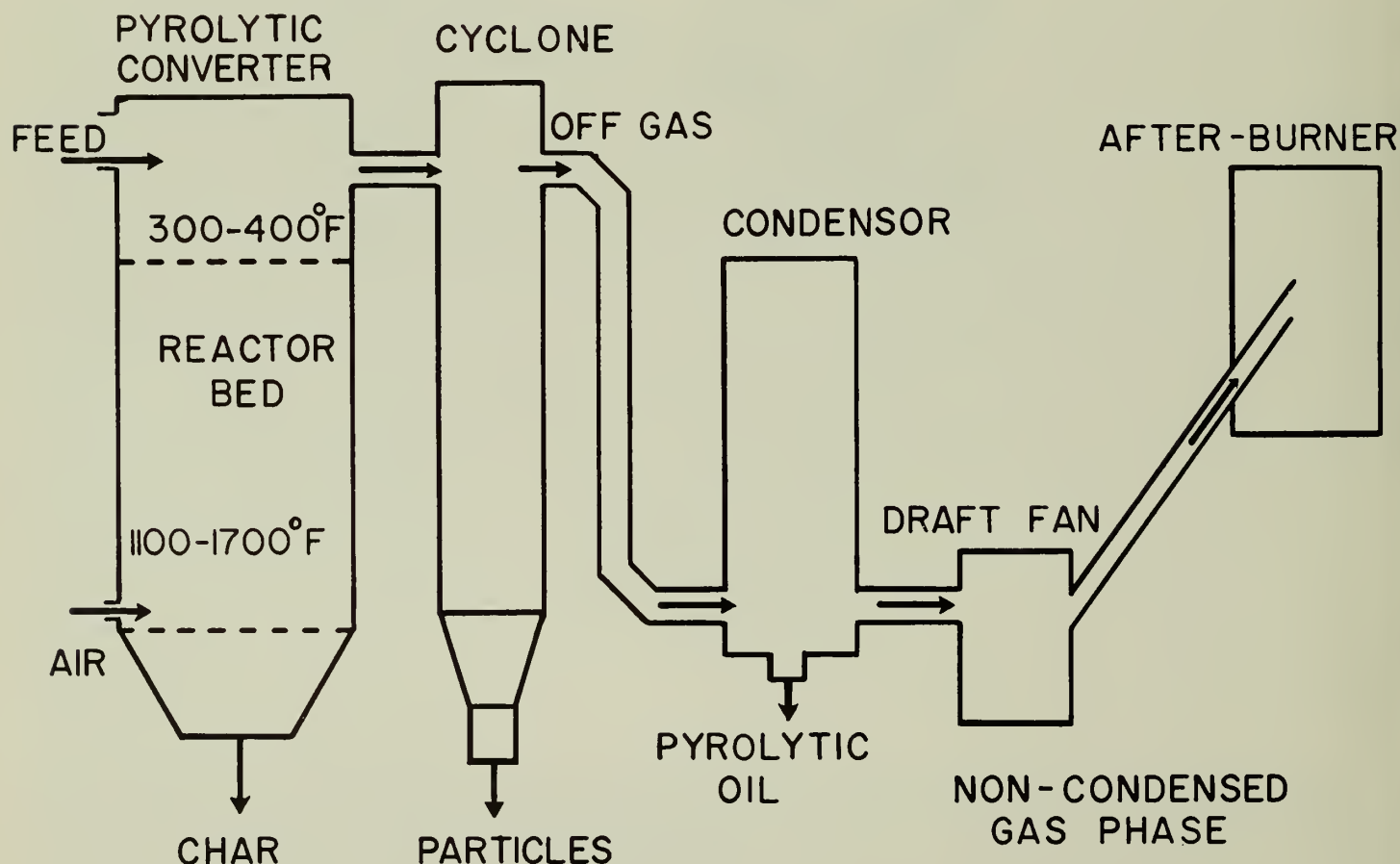


Figure 8

pipes and burners if the gas is allowed to cool or if the gas is not "scrubbed" as it exits the gasifier. These undesirable properties and grate slugging or burnout have been the most formidable problems researchers have faced.

The several concepts being developed for gasifiers at present include updraft gasifiers, downdraft gasifiers, cross flow gasifiers, and fluidized bed gasifiers. Figure 9 shows an updraft gasifier, but the same basic principles are involved in all units.

The gasifier vessel is filled with wood chips and a small fire is started on a grate above the ash hopper. Just enough air is introduced into the unit to support a glowing bed of coals. Steam may be injected into the bed to promote the formation of hydrogen ( $H_2$ ) and to control grate temperature. In the reduction zone, the hot gases from the combustion process are partially reduced to carbon monoxide (CO), a low heating value gas. The products then pass into a pyrolysis zone where the infeed first gives up its volatile gases.

In the top section of the updraft unit, a drying process occurs wherein the exiting product gases give up some of their heat to the infeed. The gas is drawn off at the top of the unit and piped to a burner or engine for final combustion. Due to the various gasifier configurations being developed by different manufacturers, the gases produced differ somewhat in their contents.

In general, the main barriers to full scale commercialization of gasifiers include the following:

- 1) Lack of long term operational experience by current manufacturers
- 2) Potential problems in piping and burners resulting from tars and other liquids in gas
- 3) Slagging of grates due to ash contained in wood
- 4) Requirements for operator attention

One of the most attractive aspects of wood gasifiers is price. As mentioned earlier, package wood boilers may cost 3 to 4 times as much as the natural gas/fuel oil boiler that has been the mainstay of the commercial market for the past thirty years. Cost figures indicate that gasification systems can be retrofitted to an existing gas/oil burner for substantially less than the cost of a new wood system.

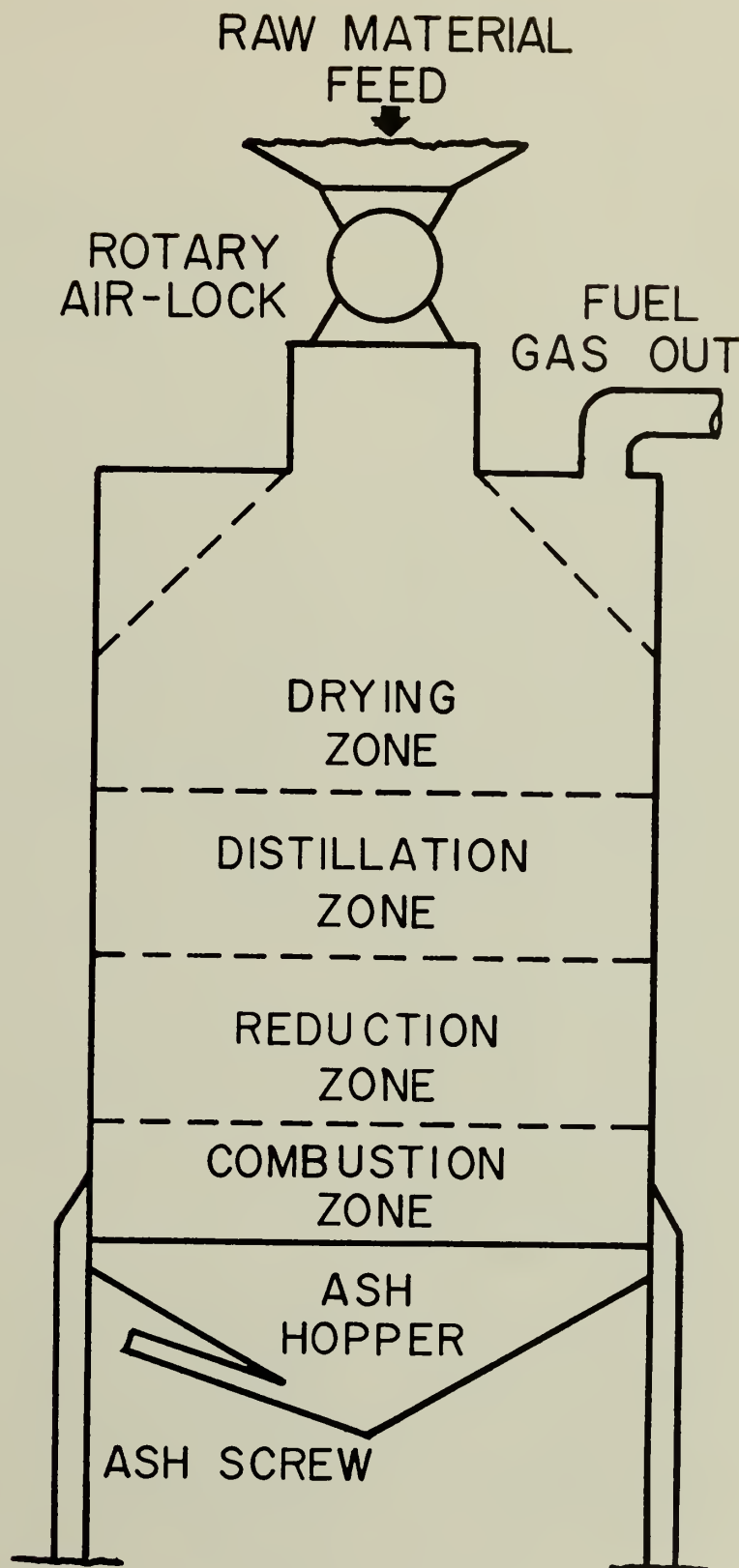


Figure 9  
UPDRAFT WOOD GASIFIER

## FIELD-ERECTED BOILERS

The last category of wood burning systems considered here is probably the most specialized. This category is field erected wood burning boilers, and each application is very site specific. Due to the labor intensive nature of the field erected boilers, they are generally much more expensive than small package boilers: most have a capital cost of at least \$35 per lb/hr of steam produced. Industrial users with a small or medium size steam requirement will probably stay away from the field erected units. Many paper mills in this country have large "bark" or "combination" (bark plus oil and gas firing) boilers capable of producing 400,000 lb/hr to 500,000 lb/hr of superheated steam for process use and electric power generation. Operating pressures may exceed 1200 psi.

Virtually all field erected boilers are watertube boilers and most use steam drums to separate the water and steam. Most units in use today for burning wood employ some form of traveling grate or stoker feed. Entrained particulates can be a problem with these units, so some form of collector is necessary to meet air pollution codes. Units of greater than 250 million Btu/hr input generally fall under stricter regulations than the smaller boilers and are thus subjected to "best available control technology" which can mean mechanical collectors, wet scrubbers, or even baghouses.

Large field erected boilers require full time operating crews and a great deal of maintenance. They are usually only cost effective in 24-hour-per-day operations since constant startup and shutdown of these units results in insulation cracks and refractory damage. There are far fewer companies building these large boilers than the package units discussed previously, and the permitting and construction processes can easily require 3 to 4 years. A typical field erected boiler is shown in Figure 10.

## ALCOHOL PRODUCTION

### FROM WOOD

Methanol and ethanol are proven liquid fuels for transportation, particularly as alcohol-gasoline mixtures in autos. To reduce foreign oil dependence, much research emphasis has been placed on the use of ethanol produced from biomass

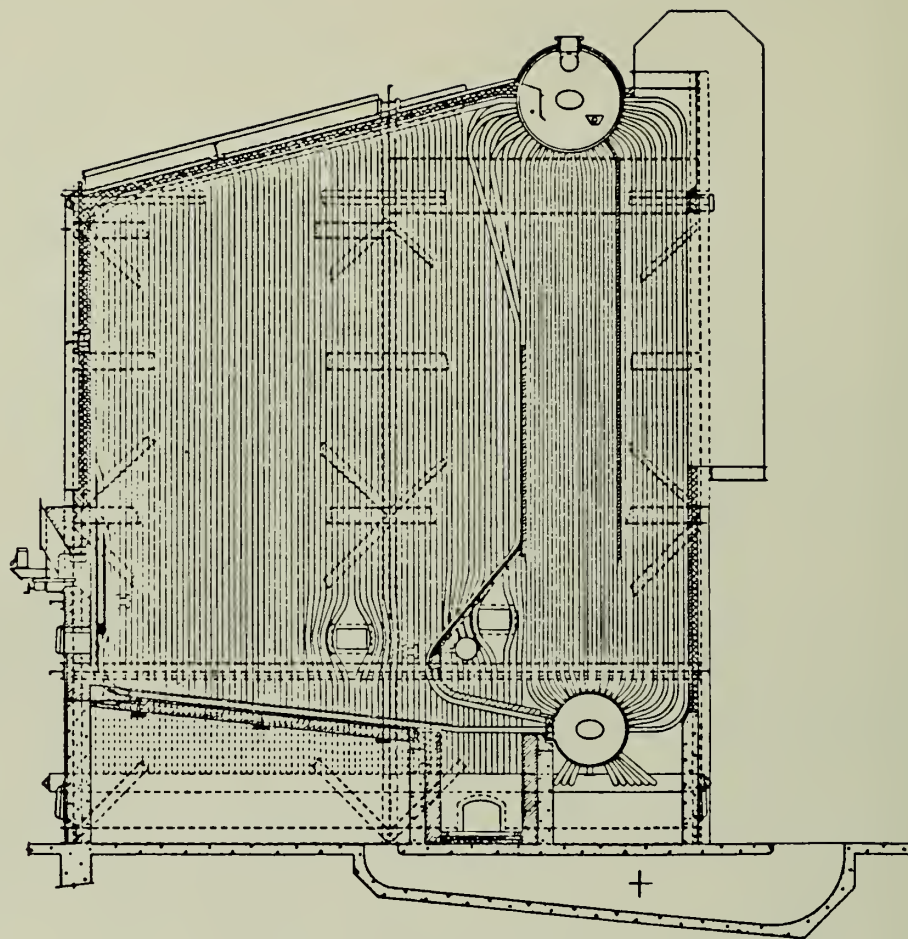


Figure 10

WOOD WASTE BOILER WITH WATER-COOLED GRATES  
(Courtesy E. Keeler Co.)

crops and residue. Methanol, also known as wood alcohol, is a relatively inferior liquid fuel compared with ethanol. Ethanol has higher Btu content, is less toxic than methanol, is miscible with gasoline, and burns well without major modification to the engine. Also, both the initial capital investment and the size of the plant required to produce methanol are considerably larger than those required for ethanol.

Much of the recent work for the production of ethanol has focused on the use of food-based products such as sugar, corn, and other grains. Wood, corn stalks, and other plant residues, however, are

more attractive raw materials since they are not part of the traditional food chain for man.

Production of ethanol from wood is an old concept. Figure 11 illustrates the process flow diagram. During World War II, a number of such plants were in operation in Europe. As single-product operations, these plants were not competitive with chemical plants based on an abundant supply of cheap petroleum as the feedstock.

A more desirable approach for producing ethanol from wood is an integrated multi-product plant where all components of wood-cellulose, hemi-cellulose, and



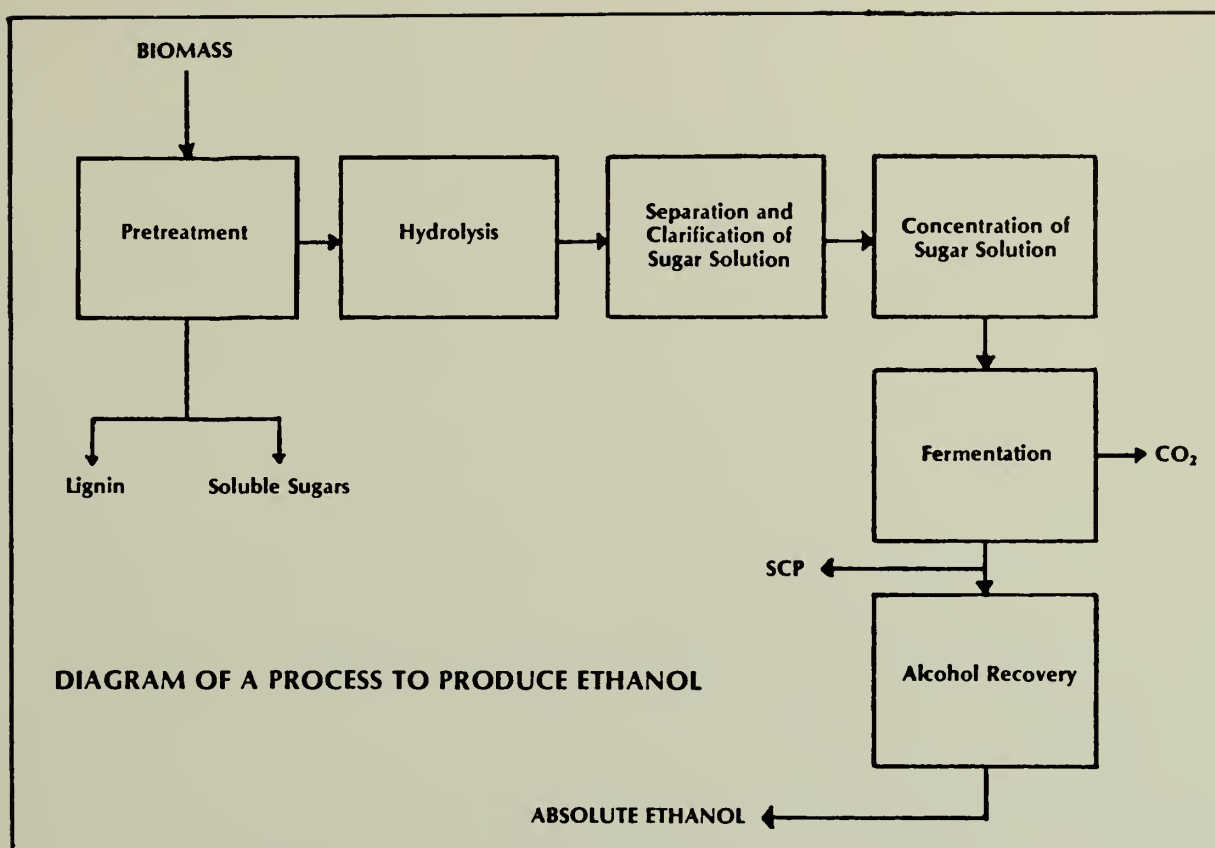


Figure 11

#### GENERAL BLOCK DIAGRAM OF A PROCESS TO PRODUCE ETHANOL

lignin--are processed, resulting in a number of valuable by-products. Lignin can be pyrolyzed into phenols, char, oil, and a combustible gas. Hemi-cellulose can be converted into pentose and hexose sugars, where the pentose can be used as a starting material to produce furfural, xylitol, single-cell protein, and also, to some extent, ethanol. Cellulose can be hydrolyzed to produce glucose, which then can be fermented to produce ethanol, carbon dioxide, and yeast.

The first stage of operation is pretreatment during which lignin is separated from the biomass and hemi-cellulose is

hydrolyzed into soluble sugars. The next stage of operation involves hydrolysis of cellulose into glucose, clarification of the solution, and concentration of the sugar solution. The third stage of operation includes fermentation of glucose into ethanol and separation of yeast. The final stage of operation is the recovery of alcohol and the production of absolute ethanol, which can be used in gasohol.

The production of ethanol can be economical only if

- 1) The raw material is available without large fluctuations in price
- 2) By-products can be sold

- 3) The crude oil price keeps going up, and

- 4) Liquid fuel becomes less available

Production of ethanol could play a very important role in reducing the dependence on the foreign supply of liquid fuel.

On the long-term basis, the ethanol produced from the renewable raw materials such as wood, agricultural residue, and crop residue, looks very promising as compared with high-priced, nonrenewable foreign crude oil.

# WOOD COMBUSTION

Combustion is the rapid chemical combination of oxygen with the elements of a fuel that will burn (Babcock and Wilcox Co., 1972).

In general, the combustion of wood can be separated into three stages. During the first stage, moisture from the fuel is evaporated. The second stage involves raising the fuel temperature to the point where volatiles are given off and combusted. The final stage is the combustion of the fixed carbons. All stages occur simultaneously in the combustion process.

## PROPERTIES OF WOOD FUEL

Dry softwoods, because of their higher resin and lignin content than hardwoods, have a higher heating value of approximately 9,000 Btu/lb. The heating value of dry hardwood is approximately 8,400 Btu/lb. Wood has a typical ultimate analysis as follows: Carbon 51.4%, hydrogen 6%, and ash 1.5%; and a proximate analysis as follows: volatile material 78.1%, fixed carbons 20.4%, and ash 1.5%. Sulfur content is essentially zero.

Properties of wood fuel vary widely, however, chiefly due to its moisture content. Wood fuel also comes from a variety of sources, and the range of particle size and form produce variation in the bulk density. Table 1 gives typical wood fuel values.

## FUEL MOISTURE CONTENT

Moisture content is generally measured on a dry basis or on a wet basis. The dry basis is commonly used by the forest products industry, whereas fuel and combustion engineers use the wet basis measure.

The dry basis measure is the fractional water content or the weight of the water in the sample divided by the sample weight when dried.

$$\text{Moisture content \% (Dry)} = 100 \left( \frac{\text{Weight of wet sample} - \text{Weight of dry sample}}{\text{Weight of dry sample}} \right)$$

Example: A one-pound sample which is half water and wood would have a wet weight of one pound. A dry weight of one-half pound a M.C. (dry) of 100%.

The wet basis measure assumes that a wood sample, divided by the weight of the wood and water to be drywood plus the weight of water. 100 percent and is the weight of water in

$$\text{Moisture content \% (Wet)} = 100 \left( \frac{\text{Weight of water}}{\text{Weight of dry wood} + \text{weight of water}} \right)$$

Example: A one-pound sample which is found to be one-half pound of wood and one-half pound of water upon drying and weighing has a moisture content of 50%.

The conversion of moisture content can be accomplished by the following:

$$\begin{array}{l} \text{Wet to Dry} \\ \text{Moisture Content (Dry)} = 100 \left( \frac{\text{M.C. Wet}}{100 - \text{M.C. Wet}} \right) \end{array} \quad \begin{array}{l} \text{Dry to Wet} \\ \text{Moisture Content (Wet)} = 100 \left( \frac{\text{M.C. Dry}}{100 + \text{M.C. Dry}} \right) \end{array}$$

The moisture content of the fuel has an important effect upon the actual heat content of the fuel. The actual heat content of a given fuel can be determined as follows:

$$\text{Actual Heat Content} = \frac{100 - \text{Wet M.C.}}{100} \times \text{Oven Dry Heat Value}$$

Moisture content of fuel is an important criteria in the design of a wood combustion system. Whereas wood boilers designed to burn green wood can usually burn dry wood, the reverse is seldom true.

Analysis of available wood supply as to quantity, moisture content, and form is recommended before making the final decision on which boiler to install.

Table 1.--Wood Fuel Properties

Wood Fuel	Moisture Content:		Higher Heating Value : Bulk Density	
	Wet Basis	Percent	Btu/lb	lb/ft <sup>3</sup>
Whole Tree Chips	50		4,500	24.0
Dry Planer Shavings	13		7,800	6.0
Green Sawdust	50		4,500	20.0
Dry Sawdust	13		7,800	11.5
Wood Pellets	10		8,100	35.0

Table 2 covers the normally encountered moisture content range.

Table 2.--Wood Moisture Content  
Wet Basis                      Dry Basis  
----- Percent -----

0	0
5	5
10	11
15	18
20	25
30	43
40	67
50	100
60	150



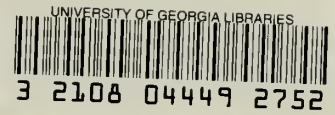


The high speed, rubber tired skidders, with hydraulic grapple, deliver the wood to the whole tree chipper. The skidder is capable of multi-stem skidding.

A feature of the feller buncher is that trees can be sheared at ground level which reduces the cost of site preparation and planting and leaves less waste material. It can handle several trees at once, piling them at a central location for skidding to the chipper.



The chipper chips the complete tree including limbs and twigs, as well as separating the commercial material.



The chip loader can group the trees, and place them where they can be engaged by power pressured rollers for entry into the chipper.



**A. Ray Shirley, Director**  
**John W. Mixon, Chief of Forest Research**